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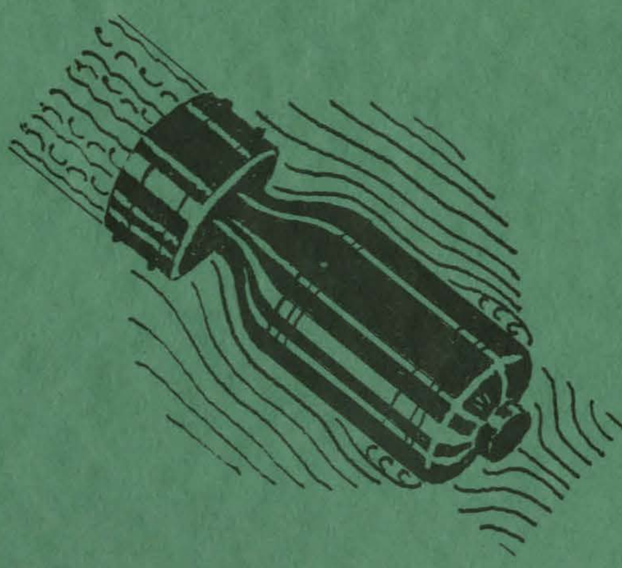
WATER TUNNEL TESTS OF THE MK 25 TORPEDO WITH GAS EXHAUST THROUGH A VERTICAL FIN



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

SECTION Nº 6.1-sr-207-1275

HML REPORT ND-30

COPY Nº 117

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WATER TUNNEL TESTS OF THE
MK 25 TORPEDO
WITH GAS EXHAUST THROUGH A VERTICAL FIN

BY

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Section No. 6.1-sr-207-1275

HML Rep. No. ND-30

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May 8, 1944

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GENERAL

This report covers tests of a 2" diameter model of the Mk 25 Torpedo conducted at the Hydraulic Machinery Laboratory of the California Institute of Technology. This work was undertaken as a part of Project NO-176. The purpose of the tests was to determine the effect of the discharge of exhaust through an orifice in the top edge of the vertical fin. Tests were made with and without a shroud ring fitted over the outside of the fins. The model was mounted in the High Speed Water Tunnel with suitable arrangements to pass a measured quantity of gas through the orifice in the fin. Runs were made with varying water velocities, water pressures, and gas quantities. Photographs were taken to show the behaviour of the exhaust gas under these varying conditions.

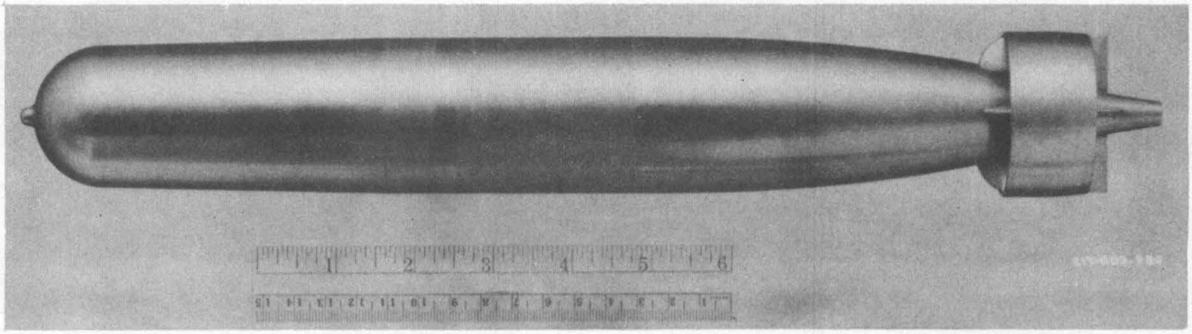

FIGURE 1
MODEL WITH SHROUD RING

Figure 1 is a photograph of the model with the shroud ring fitted to the fins. The scale ratio of the model is 1:11.21, the prototype being 22.42" in diameter and 161" long overall. Figures 2 and 3 are photographs of the model showing the exhaust orifice in the fin and shroud ring. Figure 4 shows the detail of the afterbody with the location of the exhaust orifice in the fin and shroud ring. In order to simplify the work the model was made with fixed rudders.

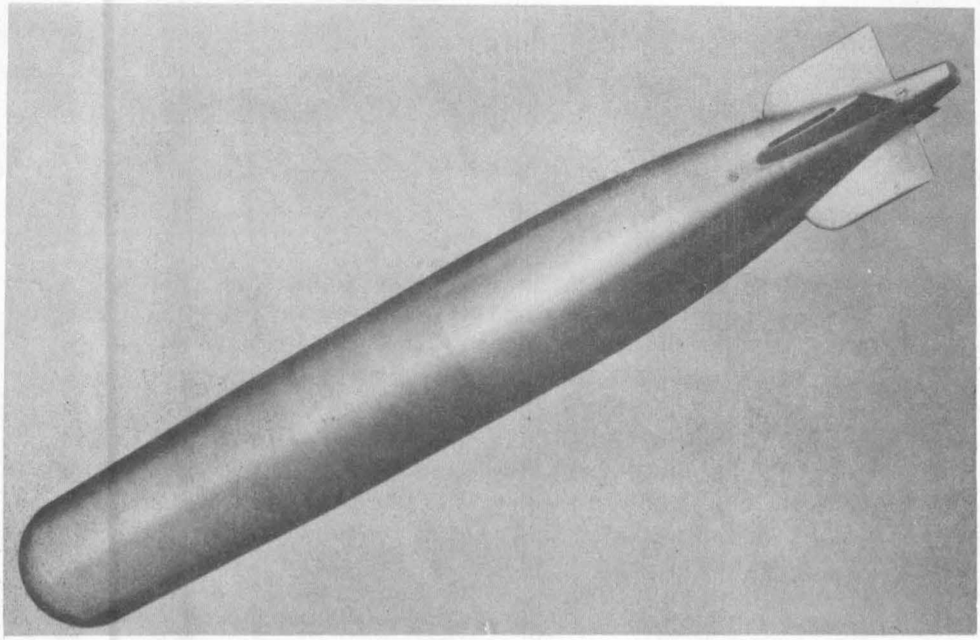

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FIGURE 2

MODEL WITH ORIFICE IN TOP OF FIN

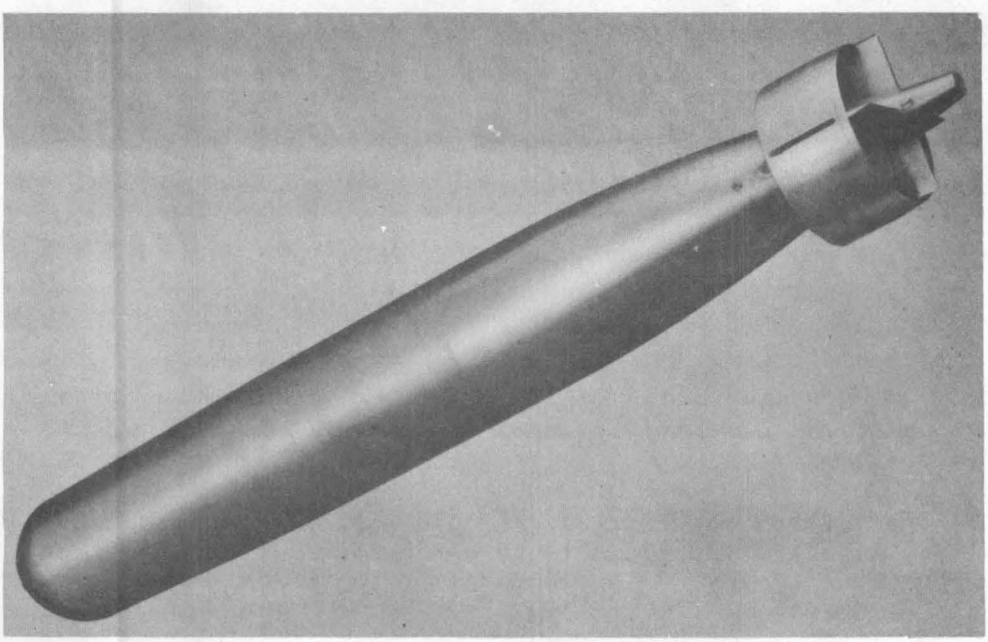

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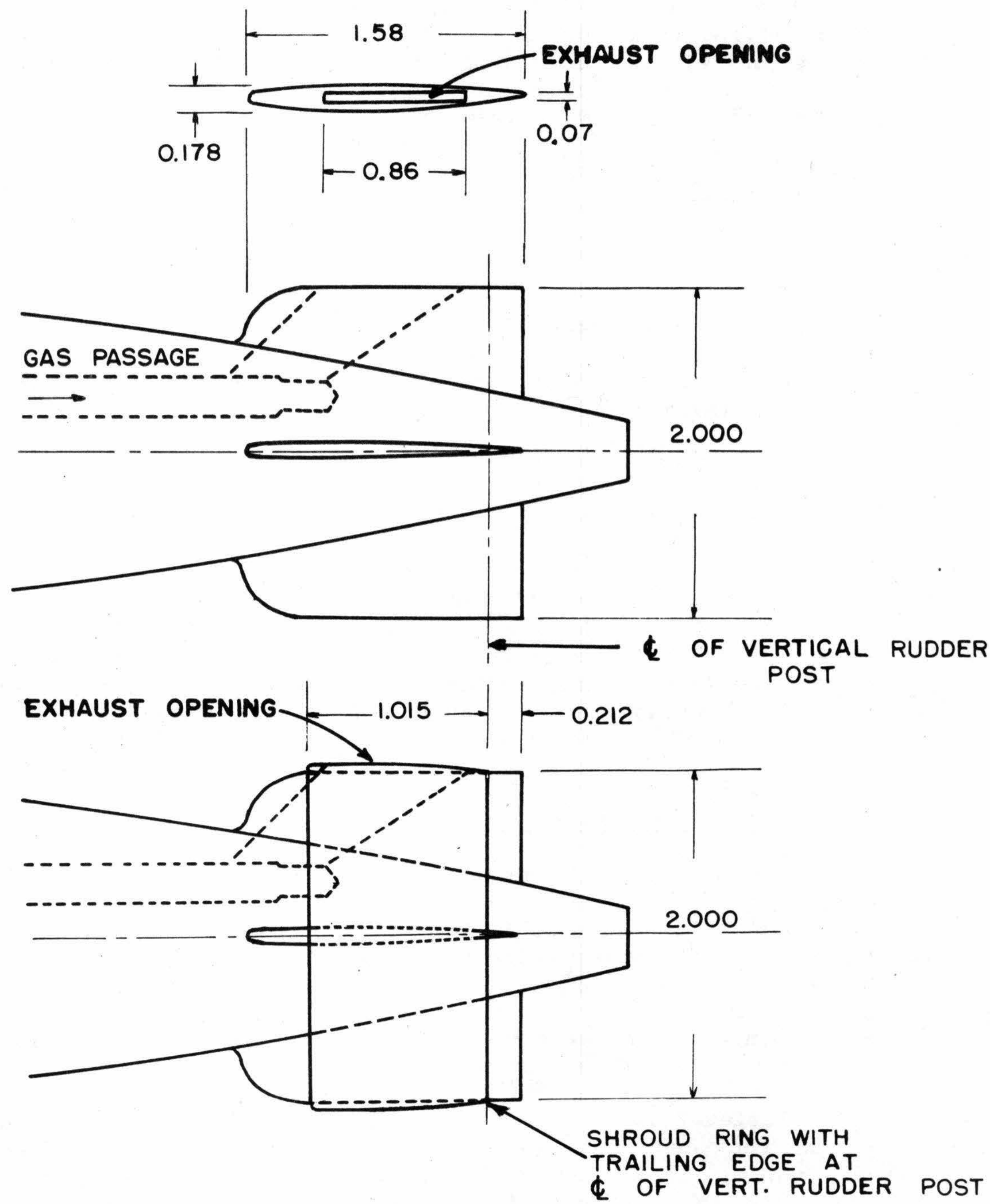
FIGURE 3

MODEL WITH ORIFICE IN SHROUD RING



DETAIL OF MODEL AFTERBODY
SHOWING EXHAUST OPENINGS

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FIGURE 4

CAVITATION PARAMETER

The air bubble formed by the discharge of gas from the fin is identical in behaviour with the normal cavitation bubble. The shape and size of the cavitation bubbles for a specific projectile can be determined by the cavitation parameter, K. This parameter is normally defined as follows:

$$K = \frac{P_L - P_V}{\rho \frac{V^2}{2}}$$

in which

P_L = absolute pressure in the liquid lbs/sq ft

P_V = vapor pressure corresponding to the water temperature lbs/sq ft

V = velocity ft/sec

ρ = mass density of the fluid in slugs per cu ft = $\frac{w}{g}$

If (P_V) is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, for equal values of K, the behavior of the bubble will be the same whether the bubble is due to cavitation or to the injection of gas as in the present tests.

CAVITATION EFFECTS WITH FINS ONLY

Figures 5, 6, 7, and 8 show the gas discharging from the edge of the fin without the shroud ring. In Figures 5 and 6 the submergence, represented by the water pressure in the tunnel, was 15 feet and the water velocity 23-1/2 and 40 knots, respectively. The corresponding values for the cavitation parameter, K, were 1.96 and 0.65. The photographs clearly show the tendency of the gas to envelop the greater part of the after portion of the fin and almost the entire area of the rudder.

Figures 7 and 8 show the effect with the submergence reduced to one foot and, consequently, a lower value of K. The exhaust gas bubble has now completely enveloped the fin and rudder and would result in severe interference with the action of the propellers and rudders.

It is understood that the amount of exhaust gas from this torpedo at 40 knots is 1285 cu ft per minute, which would correspond to 11.4 cu ft per minute of air to be discharged from the model. The test facilities were limited so the amount of air discharged from the model varied from 50% to 65% of this required amount.

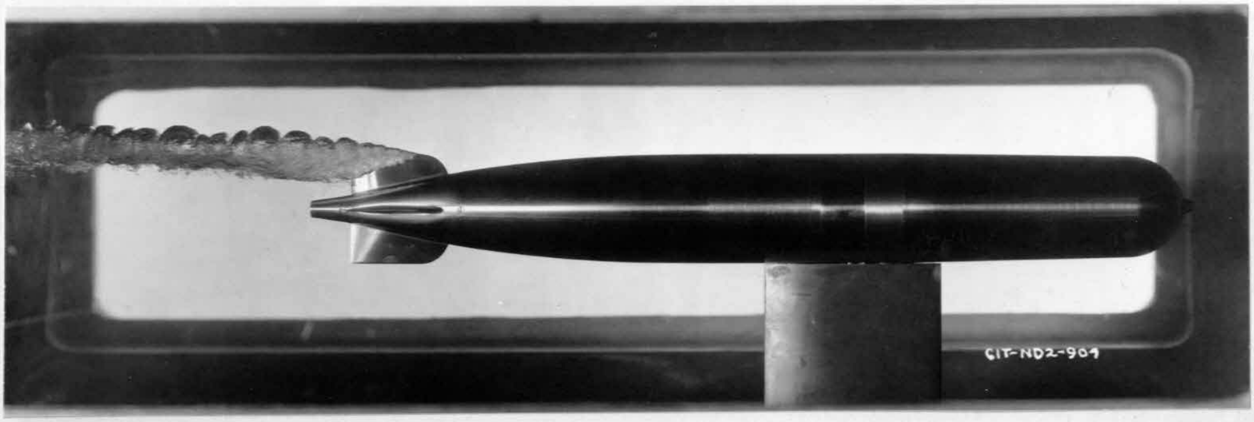

FIGURE 5

K = 1.96 SUBMERGENCE = 15 FT
V = 23-1/2 KNOTS (40 FT/SEC) GAS DISCHARGED = 6.9 CFM (60%)

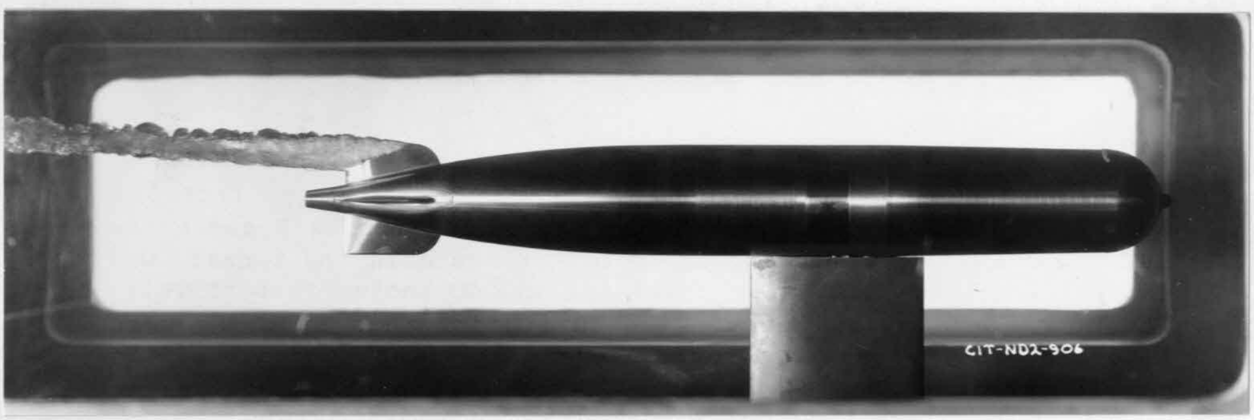

FIGURE 6

K = 0.65 SUBMERGENCE = 15 FT
V = 40 KNOTS (68 FT/SEC) GAS DISCHARGED = 7.1 CFM (62%)

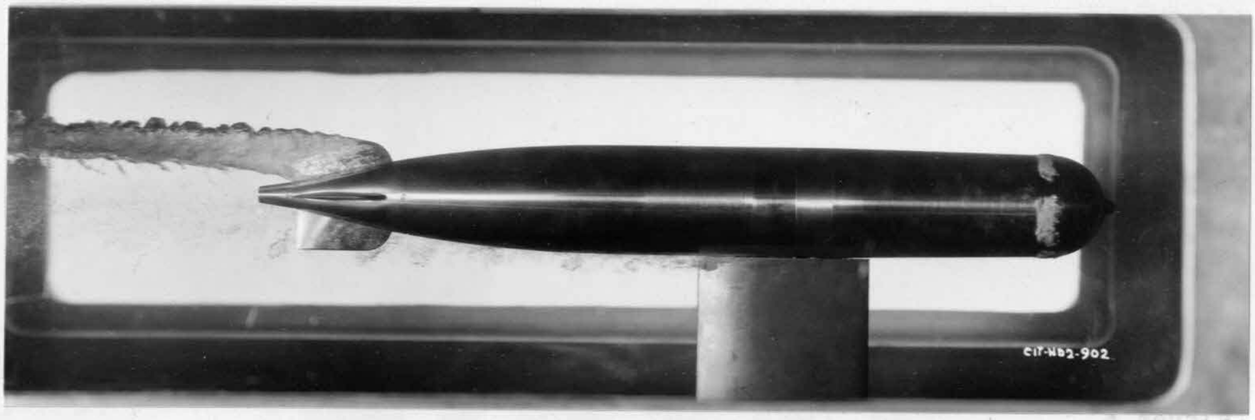

FIGURE 7

K = 0.47 SUBMERGENCE = 1 FT
V = 40 KNOTS (68 FT/SEC) GAS DISCHARGED = 9.1 CFM (57%)

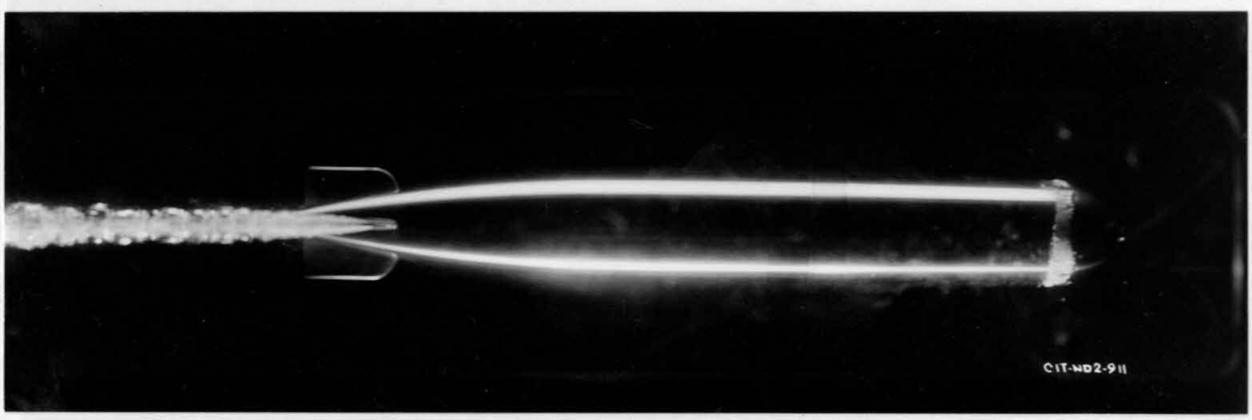

FIGURE 8

TOP VIEW OF FIGURE 7

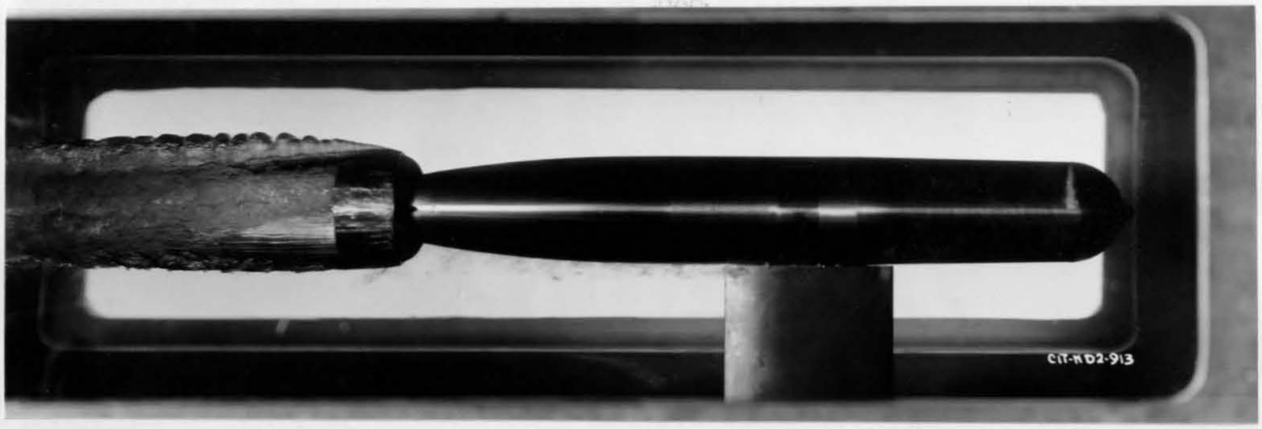

FIGURE 9

K = 0.70
V = 40 KNOTS (68 FT/SEC)

SUBMERGENCE = 15 FT
GAS DISCHARGED = 7.4 CFM (65%)

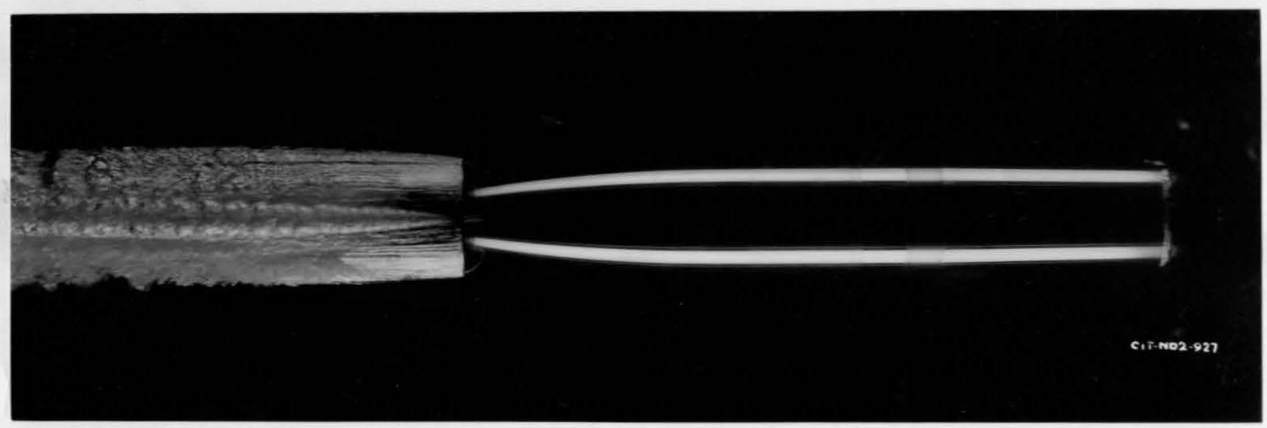

FIGURE 10

TOP VIEW OF FIGURE 9

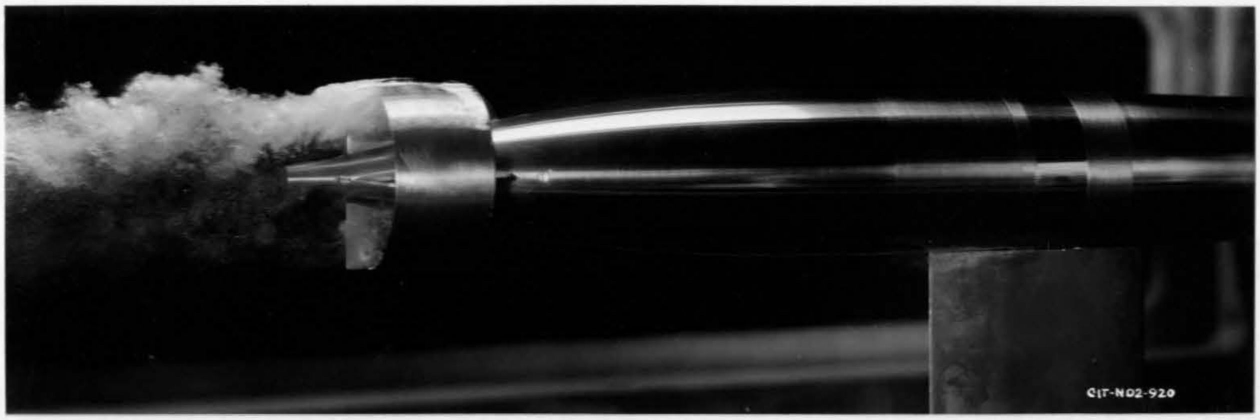

FIGURE 11

K = 0.83
V = 35 KNOTS (60 FT/SEC)

SUBMERGENCE = 15 FT
GAS DISCHARGED = TRACE

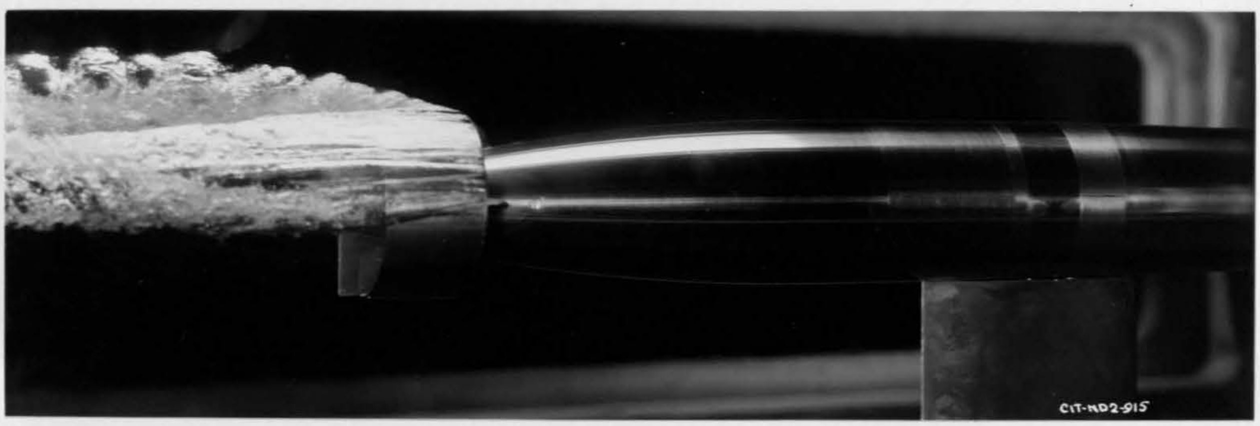

FIGURE 12

K = 1.90
V = 23-1/2 KNOTS (40 FT/SEC)

SUBMERGENCE = 15 FT
GAS DISCHARGED = 5.8 CFM (51%)

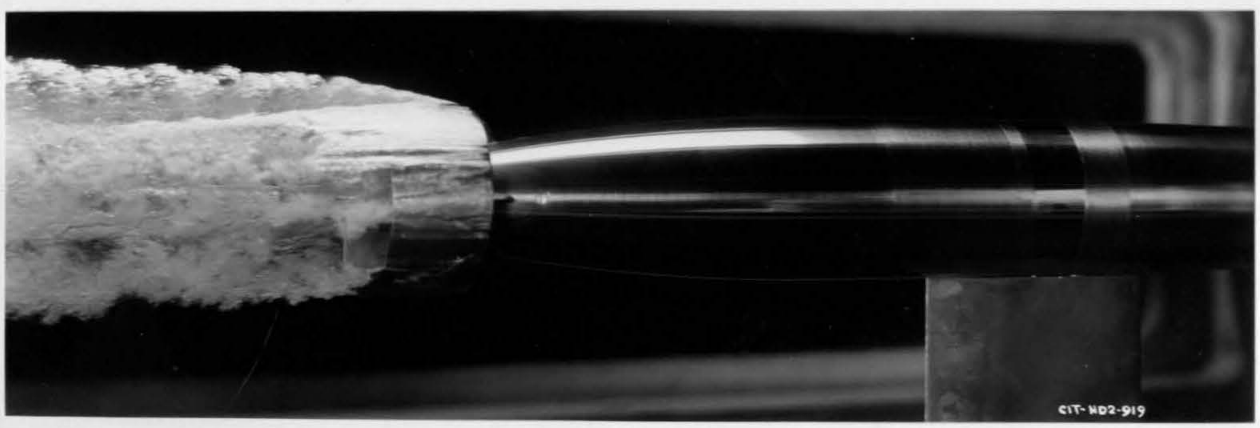

FIGURE 13

K = 0.86
V = 35 KNOTS (60 FT/SEC)

SUBMERGENCE = 15 FT
GAS DISCHARGED = 7.1 CFM (62%)

CAVITATION EFFECTS WITH SHROUD RING

Figures 9 to 13 show the conditions with the model fitted with a shroud ring. The ring was suggested in the hope that it would tend to separate the gas from the fins and thereby reduce rudder and propeller interference. The effect of the ring, as the photographs show, is entirely detrimental.

Figures 11, 12, and 13 show the effect produced by varying the amount of gas exhausted from the fin. In Figure 11 there was only a trace of air being exhausted with a value of K = 0.83. Here it is seen that cavitation has developed along the leading edge of the ring as well as on the fins. In Figure 12, which corresponds to a K of 1.90, there is no cavitation on the exposed lower vertical fin but as the amount of air discharged is 5.8 cfm, or 42% of normal, a very pronounced air bubble has developed extending more than half way around the ring. It is probable that with this high value of K no cavitation whatever would be noticed on the ring or fins with no air discharged.

Figure 13 shows the conditions with a K of 0.86 and 7.1 cfm of air discharged, equivalent to 62% of normal. This increase in air has greatly enlarged the gas bubble which now extends across practically the full diameter of the ring and along the fins as well. Figures 11 and 13 are directly comparable as they show the conditions under similar values of K, water velocity, and submergence, the difference in the size and location of the cavitation effects being due entirely to the amount of gas discharged from the top of the ring. Figures 9 and 10 show the condition for a velocity of 40 knots, a submergence of 15 ft and a value of K = 0.65. The amount of gas being discharged was 7.4 cfm or 65% of normal. It is seen that the gas bubble is fully developed around the entire circumference of the ring. This is best shown in Figure 10, which is a top view of Figure 9. Here is seen some additional disturbance along the center of the bubble caused directly by the air issuing from the orifice in the top of the ring and it is strikingly apparent that the air bubble extends across the full width of the ring.

The cavitation appears to extend as far forward as the leading edge on the ring but does not extend to the forward edge of the fin. This is explained by the fact that the fin is a streamlined body, as shown in Figure 4, and with this shape, cavitation always forms some distance back from the leading edge. The leading edge of the ring, on the other hand, is quite blunt, which is the cause of the observed cavitation at that point.

It is noted that the air discharged does not flow outwardly any great distance from the model. This is accounted for by the fact that the dynamic pressure of the air discharged is only about 5% of the dynamic pressure due to the relative velocity of the water.

GENERAL DISCUSSION

The bubble formed by the discharge of gas from the fin behaves the same as the air bubble formed around a projectile at the entrance through the liquid interface. The latter, however, is reduced in size as the air is pumped away by the high velocity of the water relative to the projectile, while the former persists owing to the continuous supply of exhaust gas.

Consideration of these facts leads to the conclusion that there is possibility of additional troubles due to the exhaust gas from gas-driven or jet-propelled projectiles. If such projectiles enter the water at velocities high enough to form an air bubble that extends as far back as the gas discharge point, then the exhaust gas might furnish the necessary supply to replace the air pumped away by the water, resulting in a permanent bubble surrounding the projectile. Under such conditions all control by the rudders would be lost and the effect of the propellers would be practically eliminated. In addition to this, the drag for a projectile travelling within a bubble is several times as great as that without the bubble, so a serious reduction in the range of speed would result.

These tests illustrate very graphically the behavior of the cavitation phenomena. From the equation given for the cavitation parameter, K, it is seen that the value of K is lowered as the absolute pressure of the liquid and the vapor pressure of the liquid are reduced and, also, as the velocity is increased. As indicated in Figure 9, cavitation effects are first observed at the sharp corners of fins, etc., which cause a sudden increase in velocity. In this case the effects are along the leading edges of the ring and fins. As there is no air being discharged, the value of K is dependent on the difference between the pressure and the vapor pressure, the latter being a very small quantity. With the discharge of air as shown in Figure 13, other conditions for velocity, pressure, and submergence being the same, the cavitation effect is greatly extended. This is because the volume of air discharged into the bubble is great enough to materially lower the effective collapsing pressure in the zone of the bubble and, consequently, the value of K for this zone is also lowered. As before stated, the effective collapsing pressure is the pressure of the liquid reduced by the gas pressure in the bubble which may, in this case, be a very large quantity compared to the vapor pressure existing under normal conditions.

CONCLUSIONS

A study of the data and photographs resulting from these tests leaves no doubt that this method of discharging exhaust gases from a torpedo is entirely undesirable. It is certain that the exhausting of gas ahead of the rudders and propellers will result in severe interference with their operation, even to the extent of nullifying any rudder or propeller effect.